Energy Harvesting Eel

Ocean Power Technologies

DARPA Program: BAA-97-44, Energy Harvesting

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Future Objective

Team Members

- Ocean Power Technologies: Program Management, Systems, Power Extraction, Bias Supply
- Autonomous Undersea Systems Institute: Eel-Water Interaction, Electronics, Microprocessor
- Cambridge Advanced Technologies & Simulation: Numerical Modeling of Eel-Water interaction, formation of Eel design tool
- Princeton University: Hydrodynamics of Eel and Bluff Body, Flow Testing and Visualization
- Penn State University: Materials Research and Development
- Measurement Specialties Inc.: Material and Eel Fabrication, Materials Expertise

Program Approach

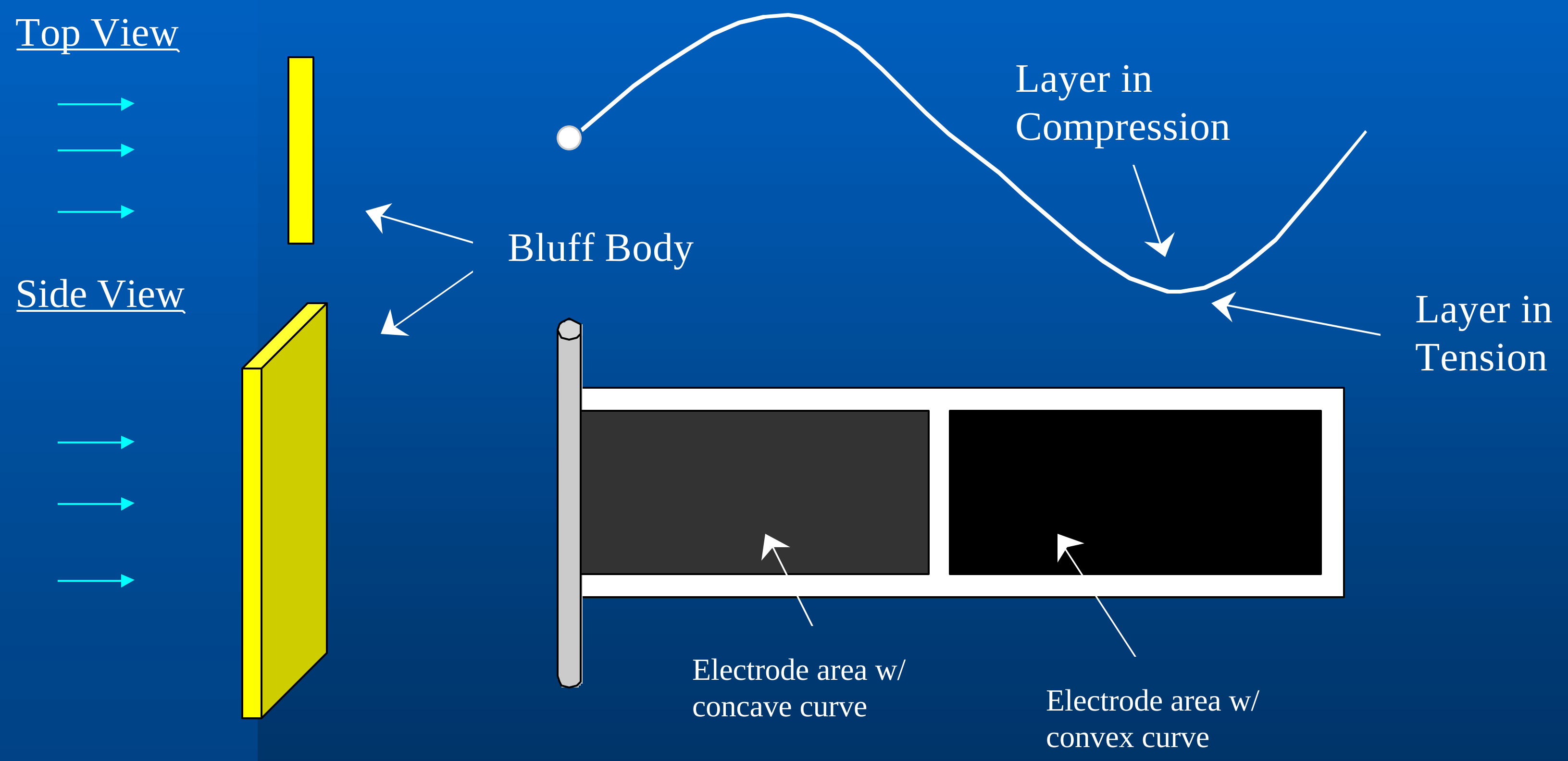
- The Eel utilizes a regular pattern of bending and unbending of a piezoelectric or electrostrictive material caused by moving water and converts it to electrical power.

- By inserting a vortex generator upstream of the Eel-like device a vortex street is generated.

- The forces generated by the traveling vortices on either side of the Eel produce a forcing field on the body. Present simulations are underway to reveal the optimum cross sectional Eel geometry based off of these forcing fields.

- The Eel currently is made up of piezoelectric PVDF, electrostrictive PVDF:TrFE copolymer is being concurrently bench tested. It is planned that the copolymer will be integrated into the system during the upcoming program year.

Illustration of Program Approach



Flowing Water → Flow Energy Converting EEL → Electricity Converting EEL → Power Electronics → Energy Storage

Program Goals

Flow Velocity (m/s)	Power @60cm^2 (Watts)	Power @310cm^2 (Watts)
1.5	2.03	10.45
1	0.60	3.10
0.5	0.075	0.39
0.25	0.010	0.05

Based on experimental results a flow energy capture efficiency of 50%, a generating module efficiency of 50%, and a power electronics efficiency of 80% is assumed above. Cross sectional areas of 60 cm^2 (3"x3") and 310 cm^2 (4"x12") are used in the table.

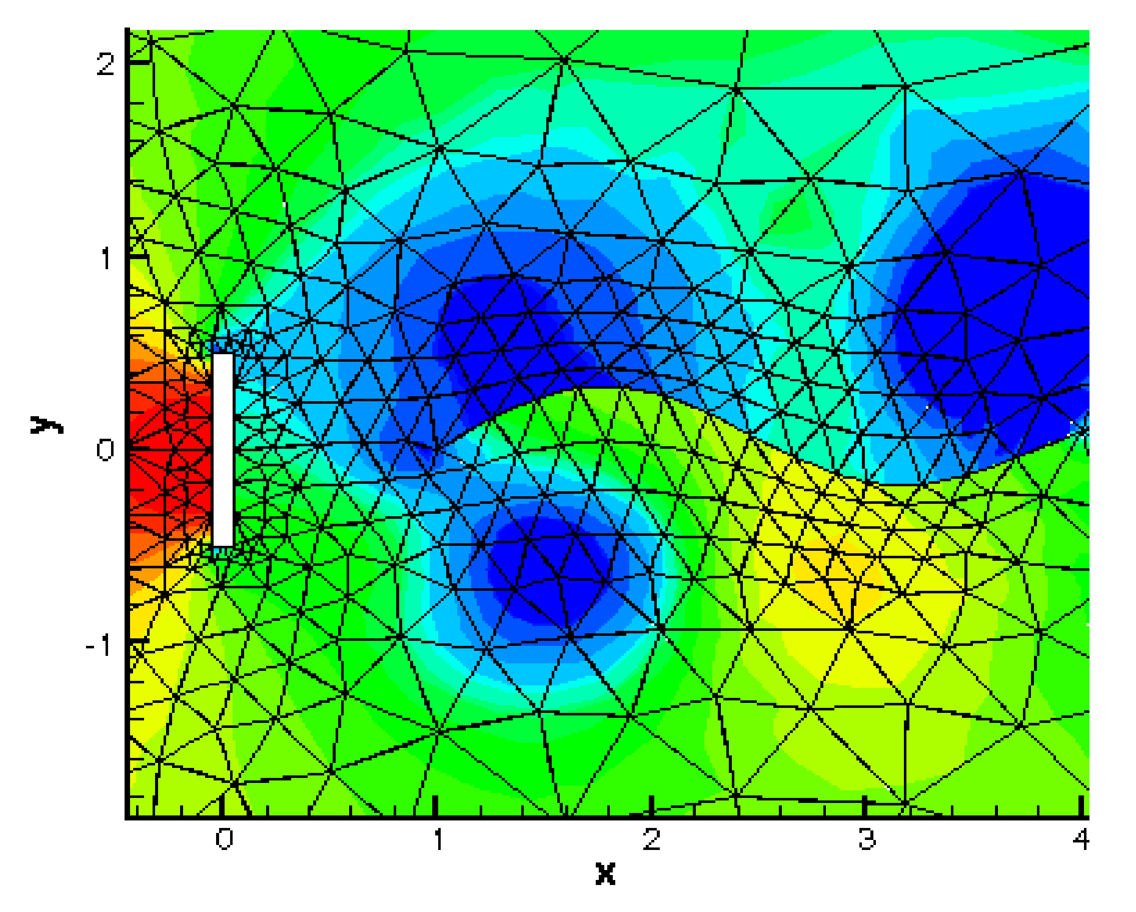
Eel Body in flow tank at .5 m/s

Positioning Rod

Bluff Body

Eel

NEKTAR
Fluid-Solid Interaction Modeling



A specific Eel length, bluff body width, and flow speed results in a forcing file.

The Eel moves in relation to this forcing field based on the inputs E, I, and m. The resulting behavior is graphically demonstrated.

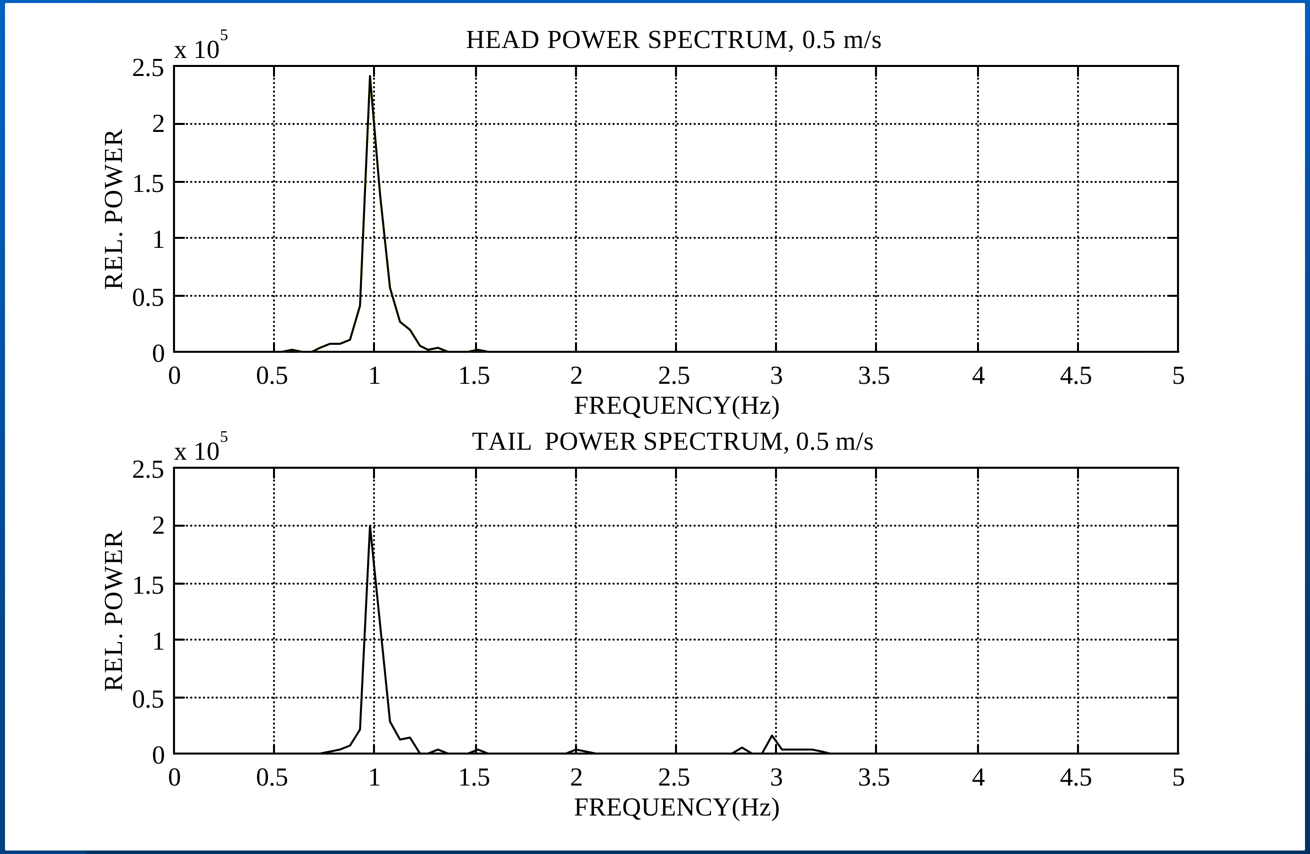
NEKTAR
Fluid-Solid Interaction Modeling

NEKTAR has been developed and run under several different Reynolds numbers, bluff body widths, and Eel lengths to produce a forcing file database.

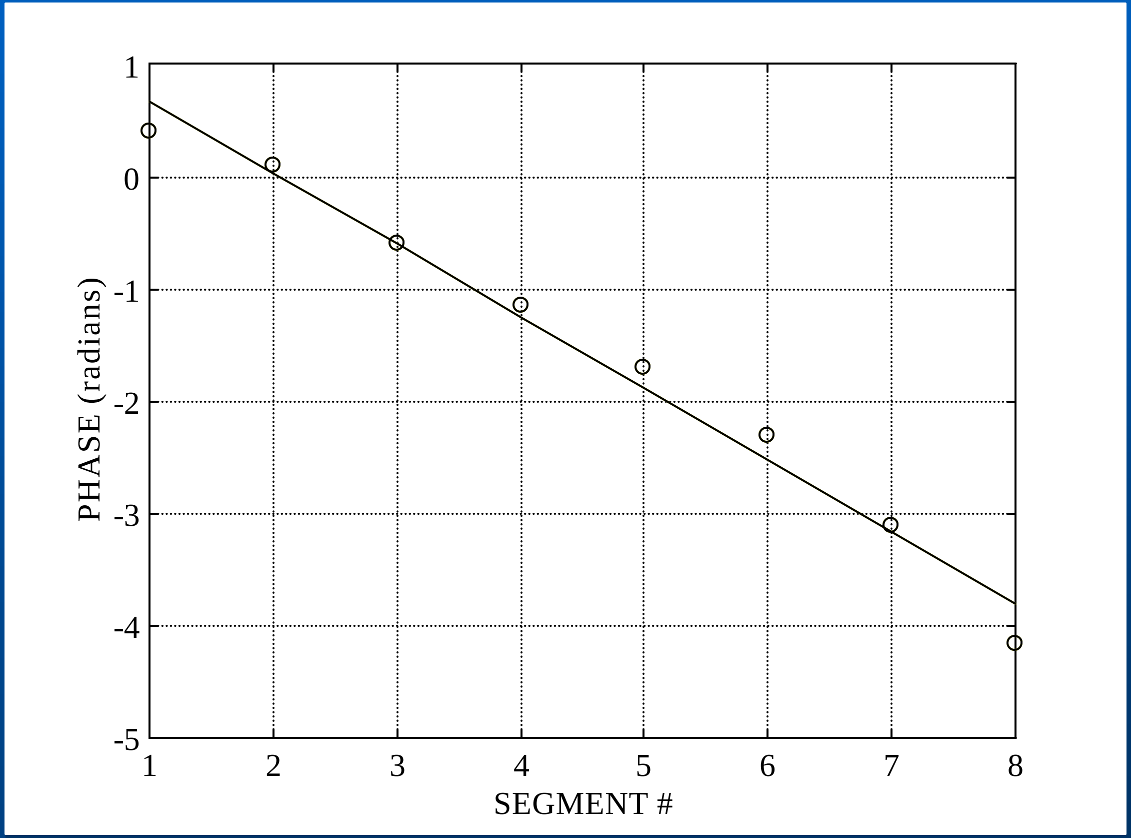
Using the database, specific Eel characteristics for any specified flow condition will be inserted and the forcing files produce the resulting Eel motion. The input characteristics include:

1) Modulus
2) Moment of Inertia
3) Mass
4) Flow Speed
5) Bluff Body Width
6) Eel Length

Power Spectrum of Electroded Eel

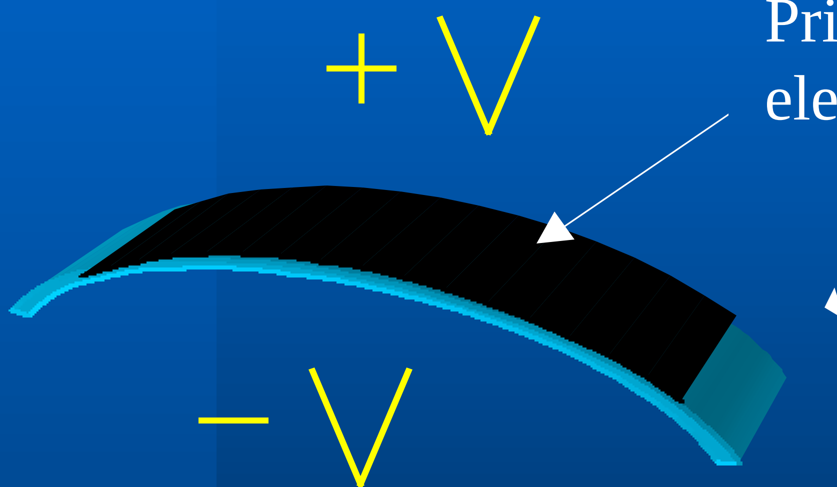


Eel Motion corresponds to Traveling Wave



Angle of Fundamental vs. Segment # at 0.5 m/s

Mechanical to Electrical Power Conversion (PVDF:TrFE)



d_{31}=120 pC/N @ 40 MV/m*

$k_{31}^2 \sim 5^1/_4$% @ 40 MV/m

∴ efficiency of 50 % with switched resonant circuit

<u>Figures of Merit</u>

$d_{31} = \varepsilon/Y\ E_B$

$k_{31}^2 \equiv c\ d_{31}^2\ Y/\varepsilon = c\ \varepsilon/Y\ E_B^2$

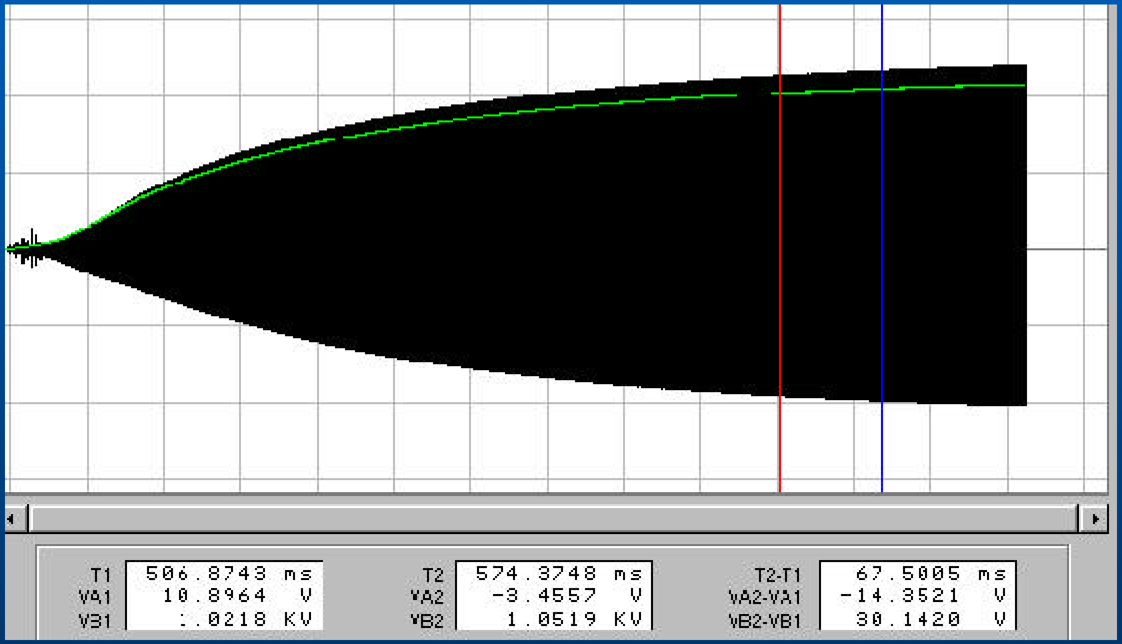
***40 MV/m =1000 V across 25 mm**

Low Power DC to High Voltage DC Converter

- Elapsed time ~ .5 seconds

- DC voltage gain: 3 Volts to ~ 1kV

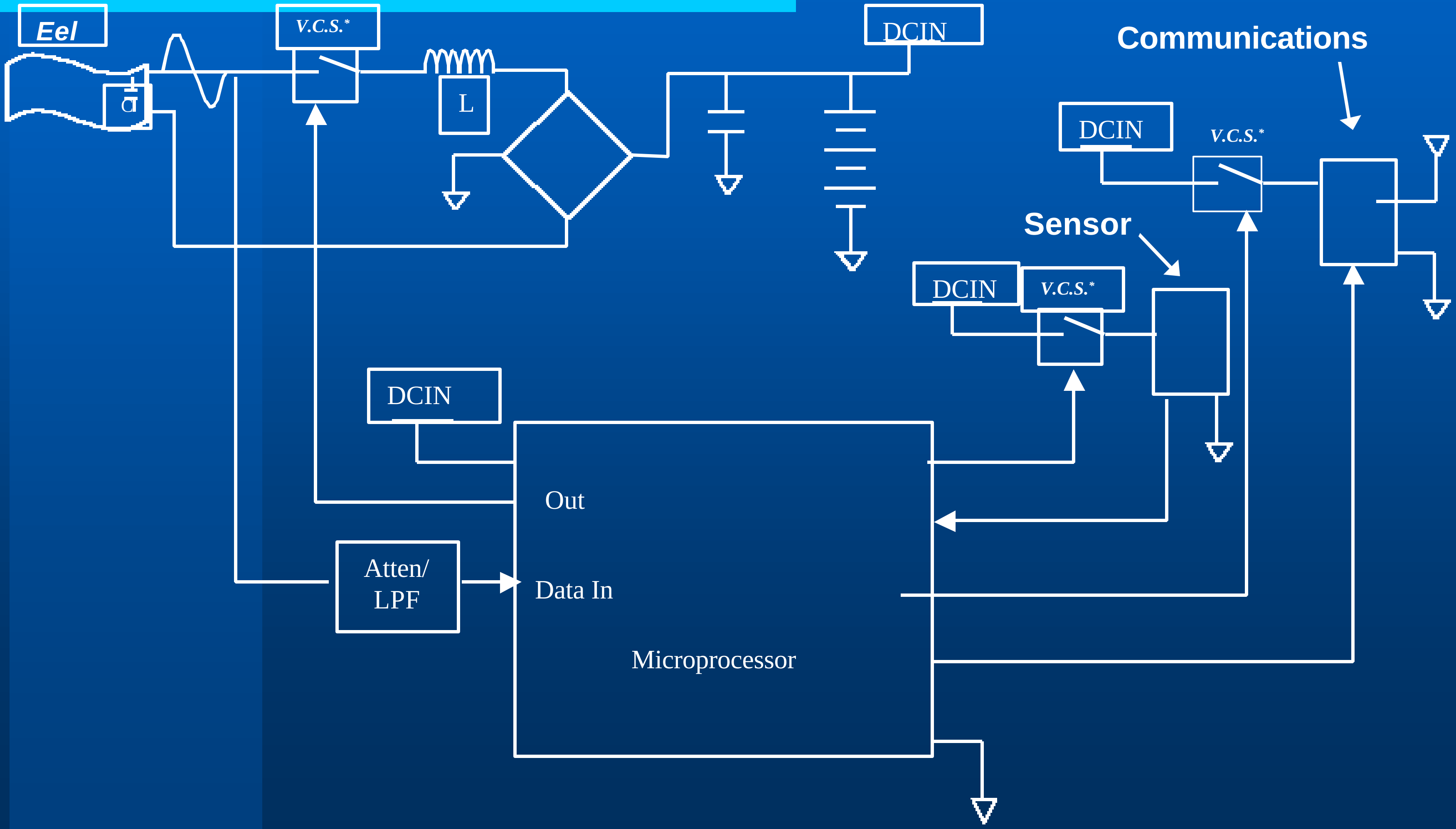
- Power required: 12 mW



Green: Bias Voltage on Capacitor

Black: Voltage on Oscillator (Low Voltage end of transformer)

Eel System w/ Battery Charging, Sensor, and Communications



How do we stack up?

Complete System Efficiency = 20 % vs. < 16 % for rotary turbine

Advantages over Turbine:

- **Broadband efficiency curve vs. steep turbine curve**
- **Operates well in low frequency environments**
- **no additional losses in gearing**

Small in size ~ 4 in^3
Light weight ~ 1/4 lb

Easily scalable

Modular design

Advantages of Eel System for Energy Harvesting

Scalable

Modular

Environmentally Friendly

Easily Deployable

Autonomous

Reliable

Can operate at low flow energy levels

Intrinsically inexpensive

Suited for covert operation

Structure suitable for mounting electronics and sensors

Applications

<u>MILITARY APPLICATIONS</u>

1) Long Term Sonar Buoys
2) power various unattended sensors

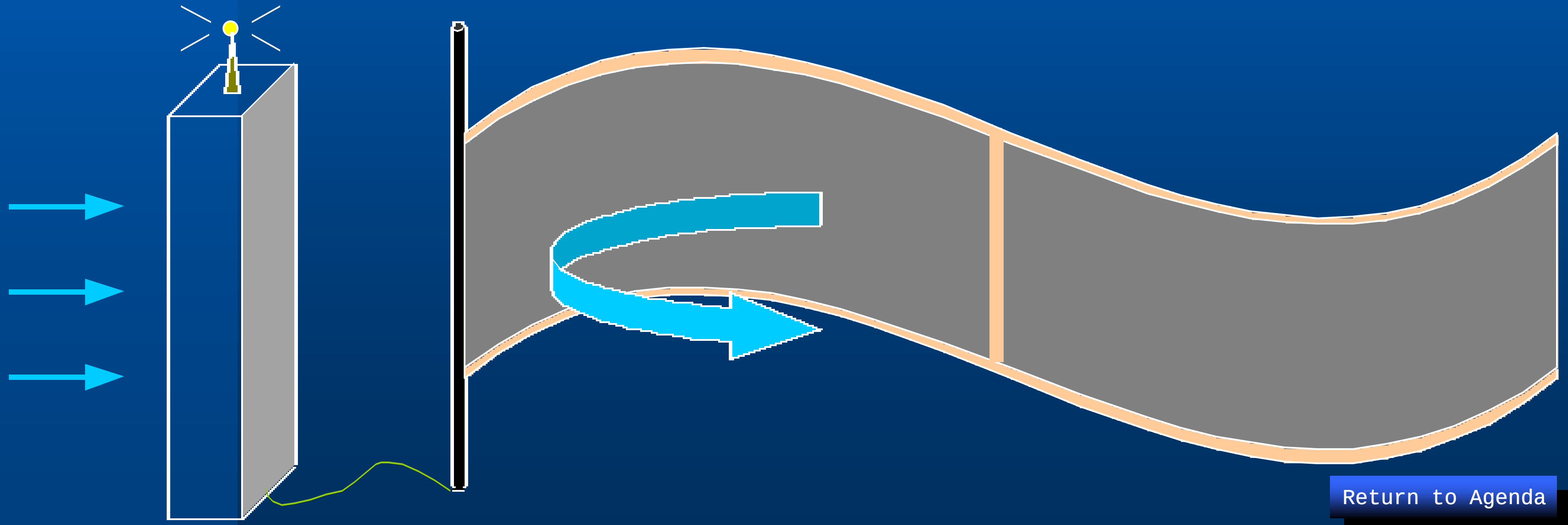
<u>COMMERCIAL APPLICATIONS</u>

1) Auxiliary power for sensing and communicating in natural gas and water transmission lines
2) Self powered and automatic communicating for oceanographic sensors
3) Short range RF communications
4) Capturing horizontal wave energy in a wave powered system

short range radio link = 50 mW of required power

The Future of the Eel

The upcoming option will be used to fully integrate the Energy Harvesting Eel into a deployable system.



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